River Wye Land Use Modelling Project using Farmscoper – Version 2

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Foreword

The condition of the River Wye is deteriorating, in part due to Diffuse Water Pollution from Agriculture (DWPA), with the increase in Intensive Poultry Units (IPUs) and high levels of legacy phosphorus in the catchment's soils receiving significant scrutiny. To support informed decision making around the actions required to address nutrient pollution issues in the Wye catchment, modelling was carried out using Farmscoper (a decision-support tool). Where possible, recent catchment-specific data was incorporated into the model instead of Farmscoper's default values. Modifications included using soils data from the RePhoKUs report and livestock data obtained from the Animal and Plant Health Agency (APHA).

The Farmscoper model was used to predict the potential reductions in nutrient loading in the River Wye which could be achieved under various management scenarios. The findings of this report will form part of the evidence base underpinning updates to the River Wye Nutrient Management Action Plan and the development of the Diffuse Water Pollution Plan (DWPP), as well as informing the delivery of farm advice within the catchment.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

Background

The River Wye (Figure 1) is one of the longest, near natural rivers in England and Wales, with the Wye and main tributary the Lugg designated as Sites of Special Scientific Interest (SSSI) and the Wye designated as a Special Area of Conservation (SAC). The river is of special interest for its aquatic plant communities, exceptionally diverse invertebrate assemblage, and wide range of migratory and non-migratory fish species. However, there has been widespread reporting on the deteriorating ecological status of the River Wye, highlighting the significant agricultural intensification of the catchment (especially a large increase in the number of intensive poultry units), chronic algal blooms and fish kills.

This project was designed to contribute to an update of the Wye Nutrient Management Plan (NMP), using the Farmscoper model to understand the scale of interventions required within the catchment to reduce nutrient loading to levels compatible with the site's conservation targets.

Modelling

The Farmscoper v5 model was applied to the Wye catchment (the English and Welsh parts) to predict the impacts of various scenarios of mitigation measure implementation. The default data within the Farmscoper Upscale N2K workbook was updated to reflect more recent data on livestock numbers provided to Natural England for use in this project by the Animal and Plant Health Agency (APHA). The mitigation scenarios considered were:

1. No measure implementation
2. Current implementation of all measures
3. 100% compliance with regulatory measures, current implementation for other measures
4. 100% implementation of the CSFO recommended measures
5. 100% implementation of the Top 5 measures
6. Maximum possible reduction achievable through measures
7. Land use change, based on the 30x30 targets.

Outputs

The APHA data suggested there are almost 30 million poultry within the Wye catchment. Combining this with the livestock excreta data within Farmscoper shows that poultry excreta is the dominant livestock source of excreta in the catchment for both phosphorus (63% of all excreta) and nitrate (49%), with amount of phosphorus and nitrate in the excreta comparable to the amounts applied across the catchment through manufactured fertiliser. However, despite the significant excreta and manure inputs into the catchment, Farmscoper predicts over half of the phosphorus loss is associated with the sediment movement, and thus controlling soil loss is a key mechanism for reducing overall phosphorus losses, with cover cropping the most effective measure as it limits erosion on land that might otherwise be bare over-winter.

Full regulatory compliance was predicted to have a small impact relative to Farmscoper's estimate of current measure implementation (6% reduction in phosphorus losses, 2% for nitrate). Adoption of the Catchment Sensitive Farming (CSF) recommended measures across the catchment reduces phosphorus losses by around 14%. Maximum possible reduction in phosphorus with the Farmscoper measure library is 38% (although this is a theoretical limit as it would be impractical to implement all the measures).

To achieve greater reductions, it is necessary to implement land use change. Large scale land use change (30% of the catchment) could achieve phosphorus reductions of 45% if targeted at the most polluting farms, or 60% if combined with measures on the remaining non-converted land. Using a non-targeted approach only achieves a 20% reduction (without further measures) despite covering 30% of the land, highlighting the need to target areas with the highest losses.

Contents

Introduction

The River Wye (Figure 1) is one of the longest, near natural rivers in England and Wales, with the Wye and main tributary the Lugg designated as Sites of Special Scientific Interest (SSSI) and the Wye designated as a Special Area of Conservation (SAC). The river is designated as a habitat supporting water crowfoot and is of special interest for its aquatic plant communities, exceptionally diverse invertebrate assemblage, and wide range of migratory and non-migratory fish species. However, there has been widespread reporting on the deteriorating ecological status of the River Wye, highlighting the significant agricultural intensification of the catchment (especially a large increase in the number of intensive poultry units), chronic algal blooms, fish kills and perceived widescale loss of the water crowfoot beds.

Modelling was used to inform a Wye Nutrient Management Plan (NMP) in 2014 (Atkins, 2014), which set out the evidence base for action and the options that could form the basis of a long-term action plan. Since then, water quality targets for the River Wye have been updated and there have been significant changes to agriculture in the catchment.

The RePhoKUs (The Role of Phosphorus in the Resilience and Sustainability of the UK Food System) project has highlighted the susceptibility of the River Wye catchment's soils to phosphorous leaching, as well as the agricultural management practices within the catchment including excessive application of fertiliser (compared to the national average).

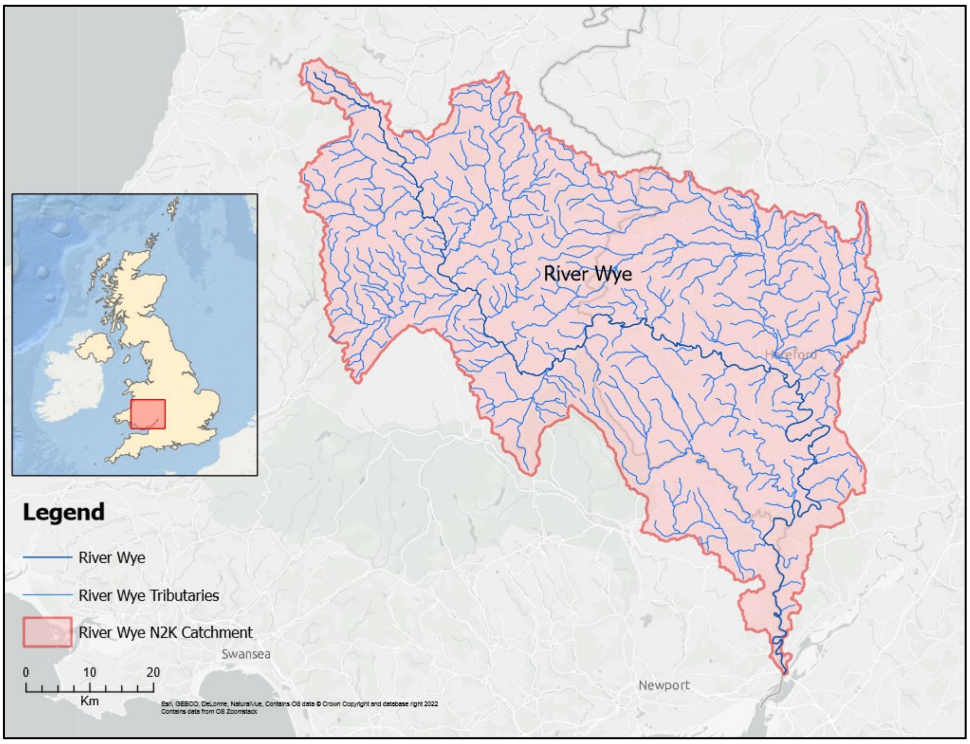

Figure 1 The River Wye catchment © Crown Copyright and database right 2022.

Project Objectives

This project is a component part of a wider programme of work to update modelling for the River Wye NMP. The aim of this component was to understand the scale of interventions required within the catchment to reduce nutrient loading to levels compatible with the site's conservation targets, using the Farmscoper model used in the original NMP. The modelling covered both the English and Welsh parts of the Wye (Figure 1).

The first task was to ensure the Farmscoper modelling is representative of the current situation in the Wye catchment, particularly those aspects that receive a lot of attention and may have a large impact on current pollutant losses. This was achieved through:

- Updating the livestock and cropping data within Farmscoper to be representative of 2021 or later, using the best available information.
- Modifying the default soil P data within Farmscoper to reflect the RePhoKus study findings.

The second task was to predict the diffuse agricultural phosphorus losses for the Wye catchment under different land management scenarios:

1. No measure implementation
2. Current implementation of all measures
3. 100% compliance with regulatory measures, current implementation for other measures
4. 100% implementation of the 2014 CSFO recommended measures
5. 100% implementation of the Top 5 measures
6. Maximum possible reduction achievable through measures
7. Land use change

Although the focus of the project is on phosphorus (note all results shown are for long term annual average total phosphorus losses), data for nitrate losses are also included.

The following chapters document the methodology used in this project, the results produced and conclude with a brief summary.

Methodology

Farmscoper (Gooday et al., 2014) was developed by ADAS in 2010 under Defra Project WQ0106(3), initially as a farm-scale decision support tool to predict the losses of nine different pollutants, to quantify the effect of implementation of one or more mitigation measures on those pollutant losses and to estimate the cost of measure implementation. Subsequent iterations of the tool with Defra and EA funding have included wider pollutant coverage, a catchment scale application and more explicit representation of the costs of mitigation. It is being extensively used by the Defra family for national policy development in the field of planning and evaluating the environmental impact of farming activities. This use is driven by legally binding requirements on the UK to reduce greenhouse gas emissions (by 80% by 2050; Climate Change Act, 2008), ammonia emissions (under the Gothenburg Protocol) and to meet standards for drinking water and good ecological status set by the Nitrates Directive (81/676/EEC) and the UK implementation of the Water Framework Directive (2000/60/EC).

Farmscoper v5 contains agricultural survey data (derived from the Defra June agriculture Survey for 2019) for the whole of England at a range of catchment scales, including water dependent Natura 2000 sites such as the River Wye. Farmscoper was used to determine long term annual average agricultural phosphorus and nitrate losses from the Wye catchment, for a baseline scenario with no mitigation measures implemented and then a number of other scenarios of increasing measure implementation.

The publicly available version of Farmscoper v5 was used, subject to modifications to the data within it to account for changes in land use and livestock numbers and differences in soil phosphorus data (described below) and to account for compliance with regulations (see Appendix).

Changes in Land Use and Livestock Numbers

Based upon analysis of CROME land use data (which is derived from satellite imagery), there have been suggestions of extensive land use change in the Wye Catchment, with the arable area increasing by 80% between 2016 and 2020 and the grassland area decreasing by 32% (EA, 2022). However, analysis of CROME data undertaken by Wilson et al (2023) suggests that the CROME data may be unreliable for detecting changes over time. Instead, summarised publicly available Agricultural Survey data was used to help quantify the extent of any land use change in the Wye. This consisted of 2016 and 2021 data for the counties of Herefordshire and Gloucestershire (Defra, 2022) and 2016 to 2020 data for Powys (Welsh Government, 2021). This data shows changes in the area of grassland and arable across these three counties of under 1% since 2016. Changes in the amount of livestock types are similarly small for most livestock types, and any modifications to the data within Farmscoper (which is for 2019) would be minor and within the uncertainty range of the data. The major exception to this is for poultry, where there has been a sizeable increase since 2016 (which has been a consistent trend for Powys). Figure 2 shows how the poultry numbers have increased over time – interpolating / extrapolating the data to allow an estimate of the change between 2019 and 2021 gives a figure of a 12% increase across the three counties.

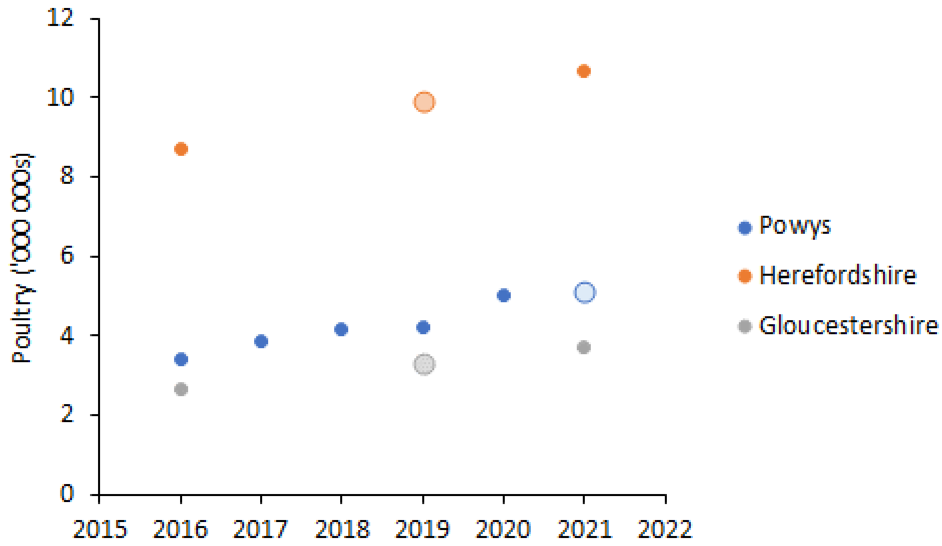

Figure 2 Changes in poultry numbers for the counties of Powys, Herefordshire and Gloucestershire over time according to published statistics from the June Agricultural Survey. Solid data points are actual data, lighter, larger data points are interpolated/extrapolated values.

However, alternative data sources suggest there may be significantly more poultry in the catchment than recorded by the agricultural survey. Data obtained by Natural England from the Animal and Plant Health Agency (APHA) and summarised by aggregate livestock categories are shown in Table 1 alongside the default data from Farmscoper. The APHA data suggests there are almost 30 million poultry within the catchment, which is almost three times the amount in Farmscoper, whilst there are only three quarters of the amount of sheep compared to the Farmscoper data. Cattle and pig numbers are very similar between the two datasets.

Table 1 Summarised default Farmscoper livestock data and the revised livestock data used in this modelling work based on APHA data.

Category	Default Livestock counts ('000s)	Revised Livestock counts ('000s)
Cattle	168	164
Sheep & Lambs	2,110	1,547*
Pigs	39	38
Poultry	10,697	29,497

*Data provided were for sheep only, this total assumes there is 1 lamb per sheep, which is comparable to the data contained within Farmscoper

Farm Type Information

The data within Farmscoper consists of livestock and cropping information, plus counts of the number of farms, by farm type, on the different climates and soils recognised by Farmscoper. The APHA data on livestock numbers (Table 1) was used in the modelling work instead of the default Farmscoper data. However, the total number of farms and number of farms by farm type were unaltered (this assumption has no impact on the overall model results, as total land areas and livestock numbers are the same). The algorithms within Farmscoper apportion the census data between the different farm types using nationally derived weightings for the likelihood of the different crops and livestock being on each farm type (these weightings produce stereotypical farms rather than average farms, as low-likelihood combinations, e.g., dairy cattle on arable farms, were removed). The results of this approach are a suite of farm types, which are then modelled within Farmscoper for each of the different climate and soil types where that farm type is found within the catchment. The results for each farm type-climate-soil combination are then multiplied by the number of farms of that combination to produce a catchment level total. Note that the land area for the Pig and Poultry farm type is larger than is typical as it includes the land that receives the manure produced from the housing units, which would normally belong to a neighbouring farm (of a different farm type).

Analysis of the initial model outputs found that too much of the land area was ending up in Farmscoper's 600-700 mm annual rainfall category because of the allocation of large areas of arable and grassland to the pig and poultry farms, which in the default data are mostly in this lower rainfall category (this allocation of land is needed to ensure the manure generated on these farms is applied at an appropriate rate[1]). Therefore, the number of pig and poultry farms in the 600-700 mm category was reduced, with an equal increase in the 700-900 mm category such that the total area predicted by Farmscoper in each of the two categories across all farm type was roughly equal (as roughly one third of the total area of the catchment is in each of these two categories).

Table 2 shows the summary cropping and livestock for the Farmscoper derived farm types in the Wye, and the total number of each farm type. The number of pig and poultry farms is very likely an underestimate given the increase in poultry numbers shown in Table 1, but since the area of these farms represents the land belonging to the farms themselves, plus the land that would receive the manure generated in any one year (which would actually be on other farms), the area per farm reported here is slightly meaningless. Extensive cattle and sheep farms are the dominant farm type, but are (on average) slightly smaller than the other livestock farm types and have lower stocking densities. Arable farms are smaller than they would actually be as much of their land is allocated to the pig and poultry farm type in order to receive manure[2].

Table 3 shows that the extensive grazing farms are assumed to occupy almost half of the agricultural area in the Wye. Pig and Poultry farms (or least the land receiving their manure in any one year) occupy one third of the catchment. Although Dairy farms have the highest stocking density (and thus are typically associated with higher pollutant loads) they only occupy 4% of the catchment.

Farmscoper has three soil types, which are designed to reflect the pathways by which water and pollutants move:

1. Free-draining soils, where water can move freely down through the soil;
2. Slowly permeable soils, where vertical movement of water through the soil profile is impeded and there is some lateral flow. Artificial drainage is required to reduce waterlogging sufficiently for effective arable farming; and
3. Slowly permeable soils as per 2, but artificial drainage is required to reduce waterlogging sufficiently for effective arable and grassland farming.

Over half of the catchment is on Farmscoper’s free draining soil type, with a third of the catchment on heavier, slowly permeable soils where under-drainage is required for

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[1] In Farmscoper, nutrient losses per unit of manure applied are not sensitive to application rates, so these adjustments are designed mainly to make the reported farm scale results sensible on a per hectare basis, but do not impact on the overall magnitude of the losses for the whole catchment.

[2] This doesn’t impact on the overall catchment scale losses, as the total arable area is maintained, and any percentage or per hectare figures for arable farms are not sensitive to the actual area of the farm.

arable farming and only 8% on the heaviest soils where under-drainage is also present on grassland.

Note that in the River Wye Nutrient Management Plan (Atkins, 2014), the assumption was made that as soils were likely to be compacted and less well draining, they should all be treated as slowly permeable (type 2 or 3 above). Whilst this would increase losses as was desired, it would do so though the drainage pathway rather than as surface runoff. This may overestimate the impacts, as drain flow has a different connectivity to surface runoff, and would mean the impacts of certain mitigation measures are not correctly represented (e.g. buffer strips, as they only impact on surface runoff). There are thus significant differences between the results of these reports due to this assumption.

Fertiliser data is derived from the British Survey of Fertiliser Practice for 2019 (BSFP, 2020), with values varying by crop type and by farm type. The other farm management information (e.g. proportion of manure managed as slurry or FYM) were left at the default values within Farmscoper – these numbers are specified by livestock type, so any consequences for total amounts of slurry and FYM dues to changes in numbers for the different livestock categories are accounted for.

Table 2 Summary cropping and livestock information for the farm types in the Wye catchment derived by Farmscoper.

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry
Number of Farms by Farm Type	837	115	2,765	234	106
Area of cropping per farm type (hectares)					
Grass	5	99	44	43	591
Rough	0	2	8	2	0
Arable	30	12	2	17	421
Woodland	3	5	4	7	69
Livestock numbers per farm type (hectares)					
Dairy	N/A	176	N/A	N/A	N/A
Beef	N/A	63	44	63	N/A
Sheep	N/A	153	515	409	N/A
Pigs	N/A	N/A	N/A	2	354
Poultry	N/A	N/A	N/A	1,823	274,255
Stocking Density (kg excretal N per hectare)	N/A	184	103	110	165

Table 3 Percentage of the agricultural area of the Wye catchment occupied by the different farm types and soil types from Farmscoper.

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
Free draining	5	2	27	3	19	**57**
Slowly permeable – drained for arable	4	1	16	2	12	**35**
Slowly permeable – drained for arable and grassland	1	0	4	0	3	**8**
Total	**9**	**4**	**47**	**5**	**34**	**100**

Soil Phosphorus Data

Farmscoper contains information on soil phosphorus data taken from nationally collated soil analysis data (PAAG, 2019). This reports the proportion of sample returns that are different soil phosphorus indices, with separate data for arable and livestock farms. This data is used within Farmscoper to calculate the losses of phosphorus from the soil[3], dissolved in surface runoff and drain flow. The RePhoKUs project (Withers et al., 2022) has collected data on soil phosphorus indices for the Wye, so this has been aggregated to the same phosphorus categories used within Farmscoper to replace the default national assumptions. Figure 3 shows that the data for the Wye has a smaller proportion in the Low (index less than 3) category and a greater proportion of soil in the Moderate (index 3) category, whilst the amount in the high category for the Wye sits between the Farmscoper values for arable and livestock farms (and thus would be comparable given the mixed farming nature of the Wye).

The default soil phosphorus data by farm type within Farmscoper has been replaced by this Wye-specific information.

[3] Farmscoper considers phosphorus losses from soil to be either dissolved (in solution) or particulate (attached to soil particles, also being mobilised and transported by surface runoff or drain flow). The potential for dissolved phosphorus loss is strongly influenced by the phosphorus saturation of the soil as a percentage of its phosphorus sorption capacity, as commonly assessed by soil available P tests. The potential for particulate phosphorus loss by erosion is a function of the residual phosphorus content of the soil, which is not commonly measured or quantified.

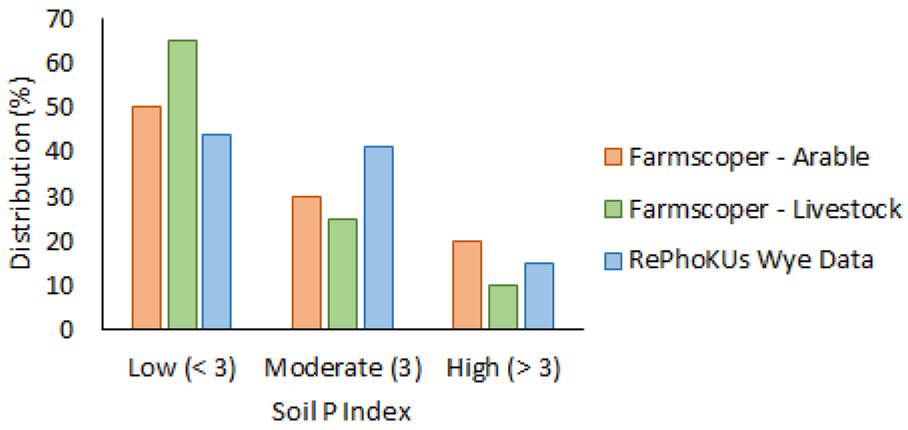

Figure 3 Soil phosphorus data within Farmscoper (derived from national data in PAAG (2019)) and from the RePhoKUs project (Withers et al., 2022) for the Wye.

Mitigation Measure Scenarios

Farmscoper includes a library of over 100 diffuse pollution control measures, based upon the Mitigation Method User Guide (Newell-Price et al., 2011), agri-environment scheme options and others that have been added during the lifetime of the tool. For each of these measures, Farmscoper contains a default implementation rate based upon national farm practice survey data, which varies by soil type, farm type and whether or not a farm is within a Nitrate Vulnerable Zone. For each measure, it also shows which policy mechanisms are relevant.

Seven scenarios of mitigation measure uptake were modelled, with some scenarios duplicated to account for a different baseline situation:

1. No measure implementation
2. Current implementation of all measures
3. 100% compliance with regulatory measures, Scenario 2 for other measures

4a. 100% implementation of the CSFO recommended measures, Scenario 2 for other measures

4b. 100% implementation of the CSFO recommended measures, Scenario 3 for other measures

5a. 100% implementation of the Top 5 measures, Scenario 2 for other measures

5b. 100% implementation of the Top 5 measures, Scenario 3 for other measures

6. Maximum possible reduction achievable through measures

7a. Land use change, plus Scenario 2

7b. Land use change, plus Scenario 6.

Reductions in phosphorus losses due to Scenarios 3 to 7 are expressed relative to both scenario 1 and 2. Reductions relative to scenario 2 are those achieved from a best estimate of current implementation, whereas those relative to scenario 1 are thus a maximum potential reduction where there is zero current implementation.

Farmscoper uses a scoring system to define current implementation of each measure, which can vary by farm type, soil type and location within a Nitrate Vulnerable Zone. This system is shown in the Appendix. Implementation rates for measures associated with regulation range from 25-100%, with lower values down to 0% for non-regulatory measures.

Table 4 Implementation rates of the different groups of mitigation measures under the different scenarios

Scenario	Regulatory Measures	CSFO Measures	Top 5 Measures	Other Measures	Land Use Change
1	0%	0%	0%	0%	N/A
2	Current	Current	Current	Current	N/A
3	Full Compliance	Current	Current	Current	N/A
4a	Current	100%	Current	Current	N/A
4b	Full Compliance	100%	Current	Current	N/A
5a	Current	Current	100%	Current	N/A
5b	Full Compliance	Current	100%	Current	N/A
6	100%	100%	100%	100%	N/A
7a	Current	Current	Current	Current	Yes
7b	100%	100%	100%	100%	Yes

The measures in Scenarios 3 to 5 are shown in Table 5,Table 6 and Table 7 respectively. The longer list of measures for Scenario 6 is included in the Appendix. Although they can be effective at reducing pollution, Farmscoper does not include measures within its measure library that directly reduce fertiliser usage, change stocking rates or alter land use, as these could distort the underlying logic for calculating mitigation uptake and impact – but they can be represented by directly altering the inputs. The land use change methodology used in this work is described later on – land use change is assumed to occur on 30% of the land, to align the with 30 by 30 targets[4] to which the government is committed.

The Farming Rules for Water (FRfW) states some activities that must be undertaken or avoided, but also lists some activities that could be undertaken as a 'reasonable precaution' to avoid pollution. The relevant measures in the Farmscoper library are identified as either FRfW required or FRfW reasonable respectively (Table 5). Based on previous work undertaken by and for Natural England, compliance with the FRfW was assumed to be 100% implementation of all 'required' measures and a minimum of 25% implementation for all 'reasonable' measures. The methodology for including this compliance is described in the Appendix. Note that compliance with the FRfW was assumed across the whole of the catchment, although the FRfW are only applicable in England. Compliance with the NVZ regulations was assumed to be 100% implementation of the relevant measures in Table 5 within the NVZ area, which is approximately 40% of the total area of the Wye (arable farms are more likely to be within the NVZ area, whilst extensive grazing farms are less likely, as the NVZ does not extend into Wales where the grazing farms predominate).

The CSF recommended measures (Table 6) are taken from the River Wye Nutrient Management Plan (Atkins, 2014). They are the measures CSFOs active in the River Wye catchment found were commonly taken up by the farmers they advised, and which were considered to be effective in mitigating diffuse water pollution from agriculture.

The Top 5 measures (Table 7) were determined by farm type, but the measures for Arable, Mixed Livestock and Housed farm types were all the same (although the order of these measures within the top 5 differed). For these farm types, the measures are focussed on reducing the losses from arable land through increasing crop cover and intercepting surface runoff. Despite the lower proportional area of spring cropping on the dairy and extensive grazing farm types, the importance of over-winter crop cover means that cover crops are still an effective measure[5]. The other measures for the extensive farm type are targeted at grassland losses due to the greater area.

[4] To manage 30% of land and sea for nature by 2030

[5] Farmscoper assumes that the arable cropping would be in a rotation, allowing the use of cover crops. On some farms, the arable crops may be used for one year in between grass leys, where there would not be the potential or need to use cover crops assuming the grass ley was established in the autumn.

Table 5 Scenario 3 - compliance with the following Farmscoper mitigation measures, which are considered to reflect the Nitrate Vulnerable Zone (NVZ) regulations and the Farming Rules for Water (FRfW). Note that the Farming Rules for Water are separated into those that are required, and those that could be considered a 'reasonable precaution' to avoid pollution.

Mitigation Measure Name	NVZ	FRfW Required	FRfW Reasonable
Use a fertiliser recommendation system	Yes	Yes	No
Integrate fertiliser and manure nutrient supply	Yes	Yes	No
Do not apply manufactured fertiliser to high-risk areas	Yes	Yes	No
Avoid spreading manufactured fertiliser to fields at high-risk times	Yes	Yes	No
Site solid manure heaps away from watercourses/field drains	Yes	Yes	No
Do not apply manure to high-risk areas	Yes	Yes	No
Do not spread slurry or poultry manure at high-risk times	Yes	Yes	No
Do not spread FYM to fields at high-risk times	Yes	Yes	No
Fertiliser spreader calibration	Yes	No	Yes
Incorporate manure into the soil	Yes	No	Yes
Minimise the volume of dirty water produced	Yes	No	No
Manure Spreader Calibration	Yes	No	No
Do not apply P fertilisers to high P index soils	No	Yes	No
Establish cover crops in the autumn	No	No	Yes
Early harvesting and establishment of crops in the autumn	No	No	Yes
Cultivate land for crops in spring rather than autumn	No	No	Yes
Cultivate compacted tillage soils	No	No	Yes
Leave autumn seedbeds rough	No	No	Yes
Manage over-winter tramlines	No	No	Yes
Establish riparian buffer strips	No	No	Yes
Loosen compacted soil layers in grassland fields	No	No	Yes
Reduce field stocking rates when soils are wet	No	No	Yes
Move feeders at regular intervals	No	No	Yes
Fence off rivers and streams from livestock	No	No	Yes
Use correctly inflated low ground pressure tyres on machinery	No	No	Yes
Locate out-wintered stock away from watercourses	No	No	Yes

Table 6 Scenario 4 - Catchment Sensitive Farming measures, as specified in the Wye NMP 2014. Measures differ for arable and livestock farm types.

Mitigation Measure Name	Arable	Livestock
Integrate fertiliser and manure nutrient supply	Yes	Yes
Fertiliser spreader calibration	Yes	Yes
Minimise the volume of dirty water produced	No	Yes
Manure Spreader Calibration	Yes	Yes
Do not apply P fertilisers to high P index soils	Yes	Yes
Early harvesting and establishment of crops in the autumn	Yes	No
Cultivate compacted tillage soils	Yes	No
Manage over-winter tramlines	Yes	No
Establish riparian buffer strips	Yes	No
Loosen compacted soil layers in grassland fields	No	Yes
Fence off rivers and streams from livestock	No	Yes
Adopt reduced cultivation systems	Yes	No
Re-site gateways away from high-risk areas	Yes	Yes
Farm track management	Yes	Yes
Establish and maintain artificial wetlands – steading runoff	Yes	No
Cover solid manure stores with sheeting	No	Yes

Table 7 Scenario 5 – Top 5 most effective measures for reducing agricultural phosphorus loss, by farm type. Measures differ for dairy, extensive grazing and all other farm types.

Mitigation Measure Name	Other	Dairy	Extensive Grazing
Establish cover crops in the autumn	1	1	2
Establish riparian buffer strips	2	4	N/A
Plant areas of farm with bird seed / nectar flower mixtures	3	5	N/A
Establish in-field grass buffer strips	4	N/A	N/A
Cultivate compacted tillage soils	5	N/A	N/A
Use slurry injection application techniques	N/A	2	N/A
Early harvesting and establishment of crops in the autumn	N/A	3	N/A
Loosen compacted soil layers in grassland fields	N/A	N/A	3
Fence off rivers and streams from livestock	N/A	N/A	4
Reduce the length of the grazing day/grazing season	N/A	N/A	1
Construct troughs with concrete base	N/A	N/A	5

Modelling Land Use Change

Farmscoper was used to model the long term annual average pollutant losses from a hectare of woodland and a hectare of zero-input (ungrazed, unfertilised) grassland, for each Farmscoper soil and climate type represented within the Wye. Livestock numbers would be reduced pro rata on the farm type being modified, including on the pig and poultry farm.

Land use change was represented by the conversion of whole farms to either woodland or zero-input grassland. The current pollutant losses from the farms converted were replaced with those of woodland or grassland for the same soil and climate type.

This would represent the long-term impact of land use change once the new land use had matured and, for slowly permeable soils, a significant deterioration in any artificial drainage systems within the soil when converting to woodland or converting from arable land to grassland on soil type 2. Any deterioration in the drainage system would reduce the amount of rapid lateral flow and thus the transport of phosphorus and sediment, whilst increasing the potential for denitrification in the now wetter soils. These impacts of drainage and denitrification are included in the losses for the land uses and soil types within Farmscoper, and so the consequences for land use change are accounted for where there is a change in soil type and/or land use under a scenario.

Results

This section describes the results of using the Farmscoper tool to model agricultural phosphorus and nitrate losses in the River Wye catchment. The first section of the results show baseline losses, including source apportionment, whilst the second section shows the impacts of mitigation measure implementation and land use change scenarios on pollutant losses. All results presented include the changes to soil P data and sheep and poultry numbers described previously.

Current Losses

Source Apportionment

To help explain some of the subsequent results, the total amount of nutrients in livestock excreta within the Wye catchment are shown in Table 8, with the apportionment in Figure 4. For phosphorus, poultry contribute about two thirds of the total excreta, with cattle (mostly beef) and sheep both contributing about 15%. For nitrogen, poultry contribute almost half of the load (49%), whilst sheep and cattle (mostly beef) are roughly equal at 27% and 23% respectively. The contribution from pigs is small for both phosphorus and nitrate (1%). The amount of nutrients in excreta are broadly comparable to the amount of nitrogen fertiliser used in the catchment, but more than four times the amount of phosphorus fertiliser - roughly 30,000 tonnes of manufactured nitrogen and 2,000 tonnes of phosphorus are applied annually (based on the average data for all land uses from the British Survey of Fertiliser Practice for 2021 of 87 kg N and 14 kg P_2O_5 ha^{-1}).

The apportionment of the annual agricultural phosphorus and nitrate losses predicted by Farmscoper are shown in Figure 5 and Table 9 – these are the losses accounting for current implementation of any measures (scenario 2). For phosphorus, losses mainly originate from residual phosphorus within the soil (which includes the longer-term contributions of fertiliser and manure applications), with phosphorus bound up within mobilised sediment the main source (54%), but phosphorus dissolved in surface runoff and drainage is also important (15%). Losses resulting from recently applied excreta, manure and fertiliser are the source of the remaining 31%, with poultry manure contributing the most (9%) followed by beef and sheep manure / excreta (7% each). The contribution of poultry manure to the total phosphorus loss is only slightly higher than the beef and sheep contributions, despite it being much more significant in terms of the amount of manure applied (Figure 4). If all other factors are equal, a unit of phosphorus in poultry manure is effectively no different to a unit of phosphorus in beef or sheep manure. The comparatively low contribution of poultry manure to the total loss (given the amount of manure) is thus a result of differences in application timings and where the manure is applied, with the beef and sheep animals located in the higher, wetter areas. Beef animals are also assumed to enter watercourses whilst at grazing and thus excrete directly into the water. Note that although the soil particulate phosphorus is the dominant source, it is potentially less bio available and may thus contribute less to any ecological impact, although the sediment to which the phosphorus is bound will cause separate issues.

For nitrate, the dominant contribution is from poultry manure (41% of the total nitrate loss), with soil (24%) and fertiliser (15%) the next two most important. Unlike for phosphorus, it is possible to determine the longer-term contributions from manure and excreta and so these are reported under the relevant livestock category rather than the 'soil' category. This large contribution from poultry manure to the nitrate losses is a consequence of both the amount of nitrogen in poultry excreta (see Figure 4) and also the highly available nature of this nitrogen content compared to other livestock manures, as well as the other livestock being more often found in wetter areas where denitrification is greater (so nitrate losses are lowered – this is in contrast with phosphorus, where losses in these wetter areas are greater, and so losses from cattle and sheep are more important).

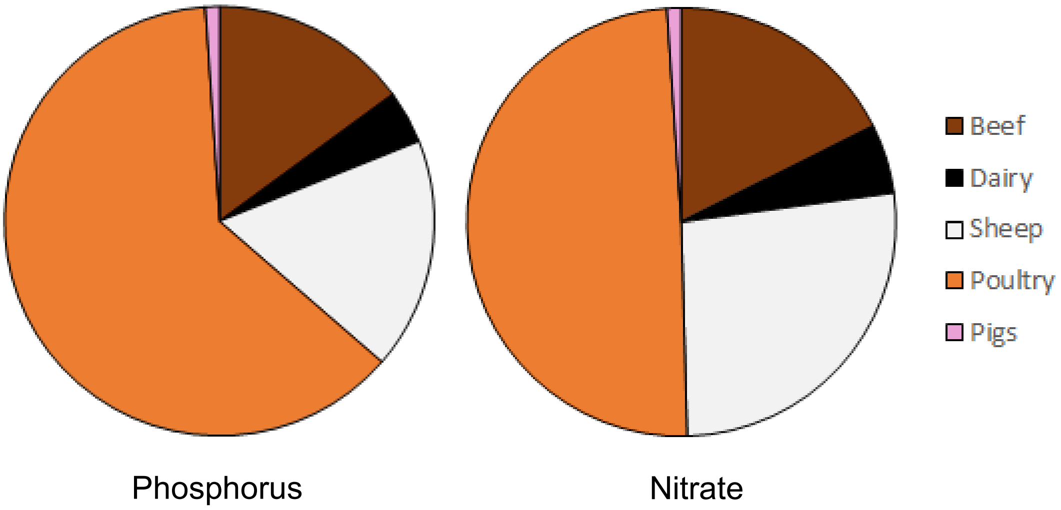

Figure 4 Apportionment of the total annual phosphorus and nitrogen excreta in the Wye catchment, by livestock type

Table 8 Annual phosphorus and nitrogen excretion in the Wye catchment, and percentage of the total, by livestock type.

	Tonnes of Phosphorus	Phosphorus % of Total	Tonnes of Nitrate	Nitrate % of Total
Beef	1,322	15	6,480	18
Dairy	354	4	1,926	5
Sheep	1,545	17	9,831	27
Poultry	5,542	63	18,169	49
Pigs	94	1	391	1
Total	8,857	-	36,796	-

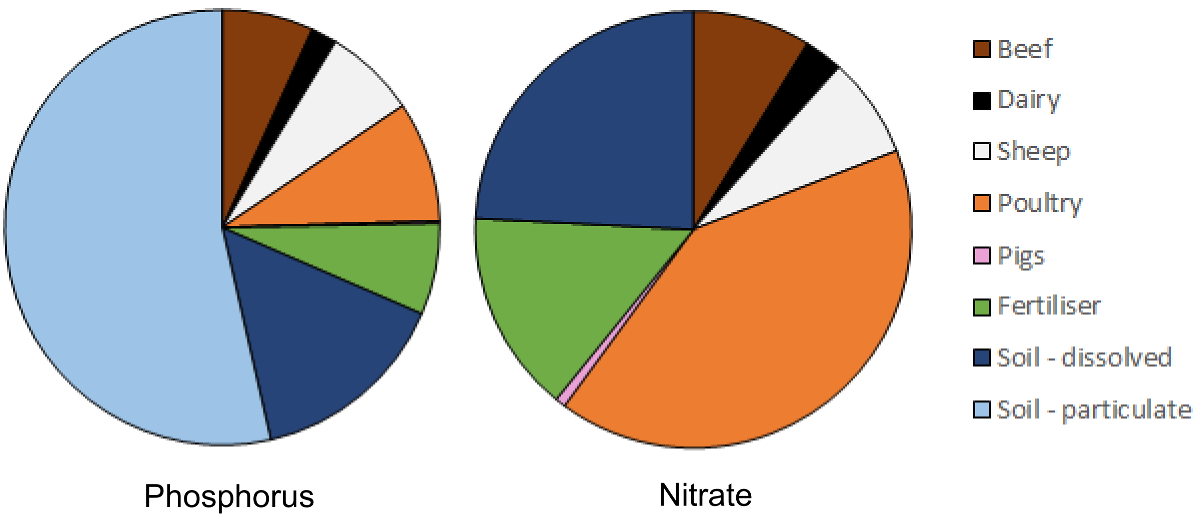

Figure 5 Apportionment of the annual average agricultural phosphorus and nitrogen loss in the Wye catchment, by source.

Table 9 Percentage apportionment of the annual average agricultural phosphorus and nitrogen loss in the Wye catchment, by source.

	Phosphorus	Nitrate
Beef	7	9
Dairy	2	3
Sheep	7	7
Poultry	9	41
Pigs	0	1
Fertiliser	7	15
Soil - dissolved	15	24
Soil - particulate	54	N/A

Current Practice

Phosphorus and nitrate loads by farm type and soil type are shown in Table 10 and Table 11. Phosphorus loads are higher on the slowly permeable soils, where drains are an efficient conduit for phosphorus transport, and thus highest on farms where both arable and grassland fields have drains. Losses are highest for the dairy farm type (0.5 kg ha^{-1}), which is the most intensively stocked and also where it is assumed cattle would have direct access to water (at grazing, and potentially crossing streams when returning to the milking parlour). Loads on the pig and poultry farm are high (0.44 kg ha^{-1}), but not as high as on the dairy farm or the extensive grazing farm on some soils, notably the drained grassland soils where Farmscoper assumes there would be ditches or other watercourses alongside every field that has soil drainage, thus potentially allowing for a lot of direct deposition by cattle - although these are the least common soils, occupying only 8% of the catchment (Table 3).

For nitrate, the highest losses are on the pig and poultry farm (54 kg ha^{-1}; Table 11), although some of this loss represents the build-up of soil organic nitrogen from manure applications, which would likely be spread across different farms whereas Farmscoper effectively assumes the same farm receives the manure year after year. Aside from pig and poultry, highest loads are on the dairy farm (36 kg ha^{-1}) and lowest on the extensive grazing farm reflecting the intensity of management. Loads are 10-40% lower on slowly permeable soils than free draining ones, primarily reflecting the greater denitrification on these wetter slowly permeable soils.

Table 10 Annual average agricultural phosphorus load (kg ha^{-1}) for the different farm types and for the whole of the Wye, by Farmscoper soil type. These results include current uptake of measures (Scenario 2)

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	All
Free draining	0.17	0.27	0.19	0.14	0.23	**0.20**
Slowly permeable – drained for arable	0.66	0.34	0.22	0.29	0.57	**0.40**
Slowly permeable – drained for arable and grassland	1.08	2.46	1.50	0.91	1.37	**1.45**
Average	**0.42**	**0.51**	**0.32**	**0.24**	**0.44**	**0.37**

Table 11 Annual average agricultural nitrate load (kg ha^{-1}) for the different farm types and for the whole of the Wye, by Farmscoper soil type. These results include current uptake of measures (Scenario 2)

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	All
Free draining	27.5	39.9	16.9	25.0	61.3	**34.4**
Slowly permeable – drained for arable	20.3	32.7	15.1	17.9	46.6	**27.5**
Slowly permeable – drained for arable and grassland	18.7	29.7	14.9	14.6	36.3	**22.6**
Average	**24.1**	**36.4**	**16.1**	**21.6**	**54.1**	**31.0**

Scenario Losses

Individual Measure Impacts

Table 12 shows the phosphorus and nitrate reductions across the whole of the Wye, following implementation of various measures, with each measure raised to 100% implementation in turn, and the implementation of other measures left as per current practice. Cover cropping is the most effective measure, reducing the phosphorus loss by 7.7% and the nitrate loss by 3.4%. There are another 14 measures that each reduce phosphorus loss by over 1%, but the impacts of these measures on nitrate are often less than a tenth of that on phosphorus. The large difference in impact between phosphorus and nitrate often reflects the importance of surface runoff for phosphorus and controlling the mobilisation and delivery of sediment (hence why buffer strips are effective), whereas for nitrate controlling manure and fertilisers losses is often more effective (see the relative importance of the different sources in Figure 5), through measures such as ‘Integrate fertiliser and manure nutrient supply‘ or reducing fertiliser by e.g. ‘Plant areas of farm with wild bird seed / nectar flower mixtures’.

A number of the CSF recommended measures are assumed to have very limited impact in Table 12. Whilst this may be true at catchment scale, that does not mean that the measures are not locally important and effective. Farmscoper cannot capture the variation in management, particularly of steadings and yard areas, and may under-represent the benefits of improving these in the instances where they are significantly below ‘average’ condition.

Table 12 Percentage reduction in the agricultural phosphorus and nitrate loss within the Wye for the top 15 most effective phosphorus reduction measures, plus the other measures in the top 5 by farm type (from Table 7) and the Catchment Sensitive Farming (CSF) measures (from Table 6). Reductions expressed relative to Scenario 2 (current measure implementation).

	CSF	Top 5	Phosphorus	Nitrate
Establish cover crops in the autumn	No	Yes	7.7	3.4
Establish *c*.6m wide riparian buffer strips	Yes	Yes	4.8	0.4
Plant areas of farm with wild bird seed / nectar flower mixtures	No	Yes	4.1	0.6
Establish in-field grass buffer strips	No	Yes	3.5	0.1
Cultivate compacted tillage soils	Yes	Yes	2.9	0.3
Loosen compacted soil layers in grassland fields	Yes	Yes	2.9	0.3
Adopt reduced cultivation systems	Yes	No	2.8	0.9
Reduce the length of the grazing day/grazing season	No	Yes	2.7	0.4
Cultivate land for crops in spring rather than autumn, retaining over-winter stubbles	No	No	2.4	0.7
Do not spread slurry or poultry manure at high-risk times	No	No	1.8	0.3
Store solid manure heaps on an impermeable base and collect effluent	No	No	1.8	0.2
Do not apply P fertilisers to high P index soils	Yes	No	1.5	0.0
Management of arable field corners	No	No	1.4	0.1
Beetle banks	No	No	1.3	0.1
Fence off rivers and streams from livestock	Yes	Yes	1.1	0.1
Early harvesting and establishment of crops in the autumn	Yes	Yes	0.96	0.80
Use slurry injection application techniques	No	Yes	0.76	0.06
Construct troughs with concrete base	No	Yes	0.71	0.22
Integrate fertiliser and manure nutrient supply	Yes	No	0.51	1.16
Cover solid manure stores with sheeting	Yes	No	0.38	0.04
Re-site gateways away from high-risk areas	Yes	No	0.37	0.05
Establish and maintain artificial wetlands - steading runoff	Yes	No	0.31	0.05
Manage over-winter tramlines	Yes	No	0.23	0.06
Minimise the volume of dirty water produced (sent to slurry store)	Yes	No	0.08	0.01
Fertiliser spreader calibration	Yes	No	0.00	0.10
Manure Spreader calibration	Yes	No	0.00	0.63
Farm track management	Yes	No	0.00	0.00

Mitigation Scenarios

Figure 6 and Figure 7 show the phosphorus and nitrate loads by farm type under the different scenarios, with Table 13 to Table 16 quantifying the percentage change in the loads, either against a baseline of no measures (Table 13 and Table 14) or Farmscoper's estimate of current measure implementation (Table 15 and Table 16). The latter quantification of the percentage change against the current measure implementation allows for an estimate of the 'likely' reductions achieved by the scenarios, whilst the former provides a 'best case' reduction where Farmscoper estimate of current implementation is not appropriate (if for example, compliance is worse in the Wye than elsewhere).

For phosphorus, there is a big reduction in loads associated with current practice (14% on average), whilst for nitrate the figure is lower (11%) and there is more variation by farm type (from 6% on grazing farm to 14% on pig and poultry). The impacts of the different scenarios are more pronounced for phosphorus than for nitrate, with each scenario typically 5% more effective than the previous one for phosphorus, whereas for nitrate scenario 5 is not much more than 5% more effective than scenario 2.

All measures (Scenario 6) reduce phosphorus loads by 45% on average (relative to no measure baseline; Table 13), ranging from 40% on grazing farms to 57% on dairy farms. Nitrate reductions are lower, averaging 23% (Table 14). This difference in maximum achievable reductions reflects the fact it is possible to reduce the mobilisation of the main sources of phosphorus (e.g. via cover crops) and also the delivery (e.g. through buffer strips), whilst for nitrate it is harder to mitigate losses without resorting to reducing inputs.

Table 17 summarises the results in a format suitable for use with SAGIS-Simcat. This tool contains arable and livestock components, and so the Farmscoper results for the different farms have been appropriately combined to produce similar totals. The Farmscoper arable farm results have been combined with half the pig and poultry farms to give the arable total (as the pig and poultry farm is roughly half arable, and an analysis of the NEAP-N data used within SAGIS-Simcat found roughly half of the pig and poultry manure went to arable land) whilst the Farmscoper dairy, extensive grazing and mixed livestock results have been combined with the other half of the pig and poultry results to give the livestock total.

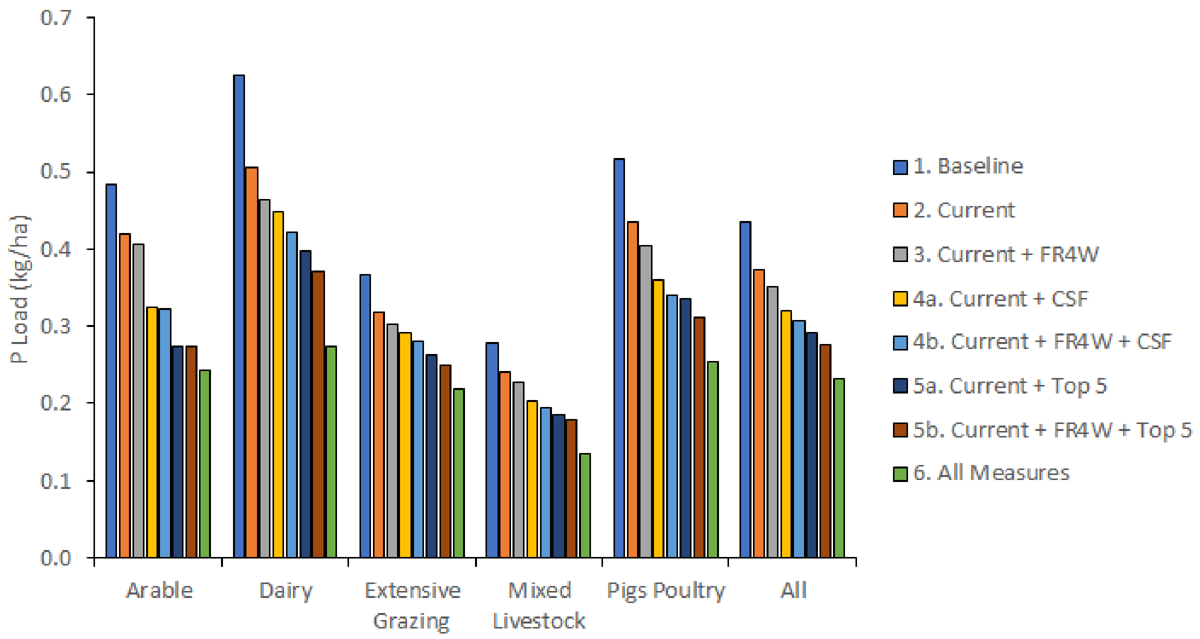

Figure 6 Annual average agricultural phosphorus load (kg ha^{-1}) by farm type and for the whole of the Wye, for all the scenarios except land use change.

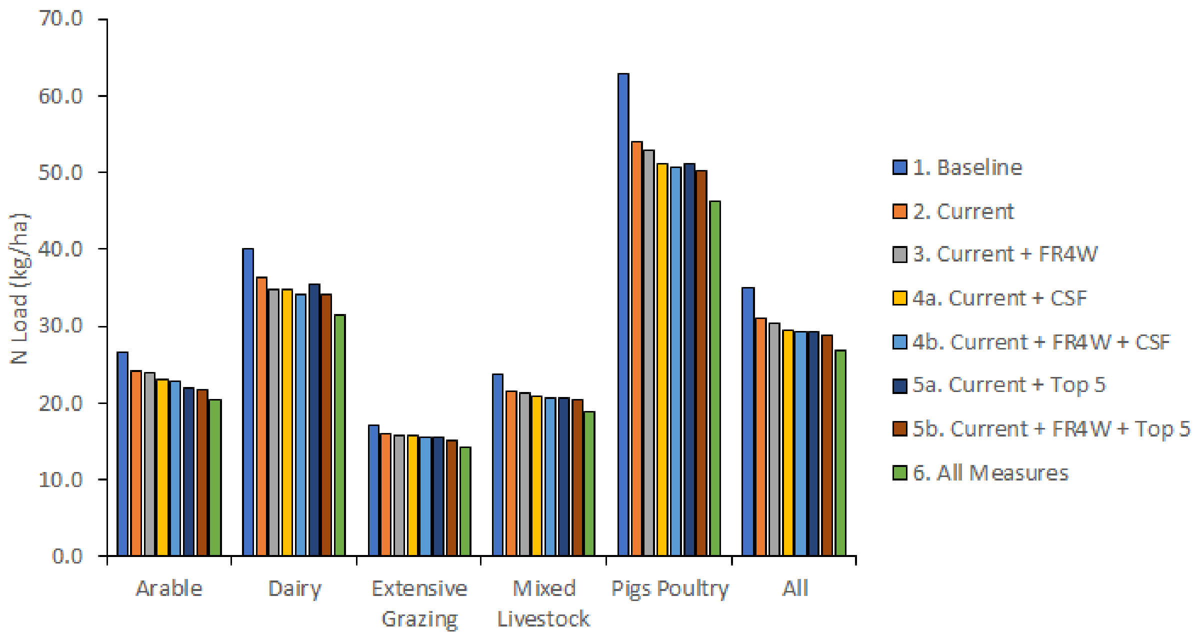

Figure 7 Annual average agricultural nitrate load (kg ha^{-1}) by farm type and for the whole of the Wye, for all the scenarios except land use change.

Table 13 Percentage reductions in the annual average agricultural phosphorus loss for the different scenarios, by farm type and for the whole of the Wye, for all the measure scenarios except land use change, with reductions expressed relative to Scenario 1 (no measure implementation).

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
2. Current	13.5	18.9	13.1	13.8	15.6	14.5
3. Current + FRfW	16.1	25.7	17.7	18.4	21.6	19.6
4a. Current + CSF	33.1	28.0	20.7	27.3	30.2	26.5
4b. Current + FRfW + CSF	33.6	32.6	23.5	29.9	34.1	29.6
5a. Current + Top 5	43.4	36.3	28.5	33.1	34.9	33.2
5b. Current + FRfW + Top 5	43.5	40.4	32.0	35.7	39.5	36.9
6. All Measures	49.7	56.2	40.5	51.3	50.6	46.8

Table 14 Percentage reductions in the annual average agricultural nitrate loss for the different scenarios, by farm type and for the whole of the Wye, for all the measure scenarios except land use change, with reductions expressed relative to Scenario 1 (no measure implementation).

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
2. Current	9.2	9.1	6.3	8.6	13.8	11.3
3. Current + FRfW	10.1	13.0	8.6	10.0	15.6	13.3
4a. Current + CSF	13.1	13.3	8.2	11.6	18.6	15.3
4b. Current + FRfW + CSF	13.8	14.8	9.7	12.3	19.2	16.1
5a. Current + Top 5	17.5	11.7	9.6	12.7	18.7	15.9
5b. Current + FRfW + Top 5	17.8	15.0	11.6	13.7	20.1	17.5
6. All Measures	23.3	21.7	17.1	20.2	26.1	23.4

Table 15 Percentage reductions in the annual average agricultural phosphorus loss for the different scenarios, by farm type and for the whole of the Wye, for all the future measure scenarios except land use change, with reductions expressed relative to Scenario 2 (current measure implementation).

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
3. Current + FRfW	3.0	8.4	5.3	5.3	7.1	5.9
4a. Current + CSF	22.6	11.2	8.7	15.7	17.3	14.0

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
4b. Current + FRfW + CSF	23.2	16.8	12.0	18.7	21.9	17.6
5a. Current + Top 5	34.6	21.5	17.7	22.4	22.8	21.9
5b. Current + FRfW + Top 5	34.7	26.5	21.8	25.4	28.3	26.1
6. All Measures	41.9	46.0	31.5	43.6	41.5	37.8

Table 16 Percentage reductions in the annual average agricultural nitrate loss for the different scenarios, by farm type and for the whole of the Wye, for all the future measure scenarios except land use change, with reductions expressed relative to Scenario 2 (current measure implementation).

	Arable	Dairy	Extensive Grazing	Mixed Livestock	Pigs and Poultry	Total
3. Current + FRfW	1.0	4.3	2.4	1.6	2.1	2.2
4a. Current + CSF	4.3	4.7	2.0	3.3	5.6	4.5
4b. Current + FRfW + CSF	5.1	6.3	3.6	4.1	6.2	5.4
5a. Current + Top 5	9.1	2.9	3.4	4.5	5.7	5.2
5b. Current + FRfW + Top 5	9.5	6.5	5.6	5.6	7.3	7.0
6. All Measures	15.5	13.9	11.5	12.7	14.3	13.6

Table 17 Annual average agricultural phosphorus loss (kg) and nitrate losses (t) and reductions (%) for the different scenarios, aggregated for use with SAGIS. Reductions are expressed relative to Scenario 2 (current measure implementation).

	Phosphorus Arable	Phosphorus Livestock	Nitrate Arable	Nitrate Livestock
Load (kg)				
1. Baseline	44,969	100,870	4,440	7,250
2. Current	38,275	86,389	3,867	6,499
3. Current + FRfW	36,111	81,169	3,795	6,346
4a. Current + CSF	30,939	76,279	3,660	6,239
4b. Current + FRfW + CSF	29,718	72,976	3,635	6,169
5a. Current + Top 5	27,978	69,381	3,621	6,205
5b. Current + FRfW + Top 5	27,978	66,972	3,621	6,132
6. All Measures	22,336	55,191	3,303	5,648
Reduction (%)				
3. Current + FRfW	5.7	6.0	1.9	2.4

	Phosphorus Arable	Phosphorus Livestock	Nitrate Arable	Nitrate Livestock
4a. Current + CSF	19.2	11.7	5.4	4.0
4b. Current + FRfW + CSF	22.4	15.5	6.0	5.1
5a. Current + Top 5	26.9	19.7	6.4	4.5
5b. Current + FRfW + Top 5	26.9	22.5	6.4	5.7
6. All Measures	41.6	36.1	14.6	13.1

Land Use Change Scenarios

Implementation of mitigation measures can be effective in reducing pollution, but to achieve greater reduction - particularly for nitrate - it is often necessary to consider land use change, as this both reduces inputs and increases ground cover. The land use change scenarios include the targeting of change at the highest or lowest polluting land to see how this impacts on the reductions achieved. Figure 8 shows the distribution of phosphorus loads across the catchment area, with over 80% of the land having an annual average phosphorus load less than 0.25 kg ha^{-1}, but 10% of the land being over 0.5 kg ha^{-1} and contributing over 25% of the total loss. Table 10 shows the importance of soil type to Farmscoper's predictions of phosphorus losses, and the top 10% are almost entirely on the slowly permeable soils requiring drainage for both arable and grassland, with farms in the wetter areas on these soils having the highest losses.

Table 18 shows the impact of the various land use change scenarios on phosphorus and nitrate losses. Converting all arable farms to zero input grassland (without any additional implementation of measures) achieves a 6% reduction in nitrate and 9% reduction in phosphorus. This is a relatively modest reduction, but a large area of the arable land in the catchment has been assigned to the pig and poultry farms in order to receive manure – if this land was also reverted to zero input grassland then it is likely there would have to be an associated reduction in livestock. Conversion to woodland rather than grassland increases the reductions by another percent or two.

If land use change is targeted at the 30% most phosphorus polluting farms, then reductions are greater than can be achieved with measures alone, reaching 45% for phosphorus and 31% for nitrate (the 'all measures' scenario achieves a 38% reduction in phosphorus and 14% reduction in nitrate; Table 15). If the non-converted land implements 'all measures' then the net reduction increases to 60% for phosphorus and 36% for nitrate. If land use change is on the least phosphorus polluting farms, then overall phosphorus reductions are only 7% if no additional measures are also used. Converting 30% of land on all farms achieves 19% reduction in phosphorus. As the targeting is based on phosphorus pollution, and there is limited correlation between phosphorus and nitrate loads (comparing Table 10 and Table 11), converting 30% of all farms achieves similar reductions in nitrate compared to targeting the high or low phosphorus load farms (27% 26% and 31% respectively).

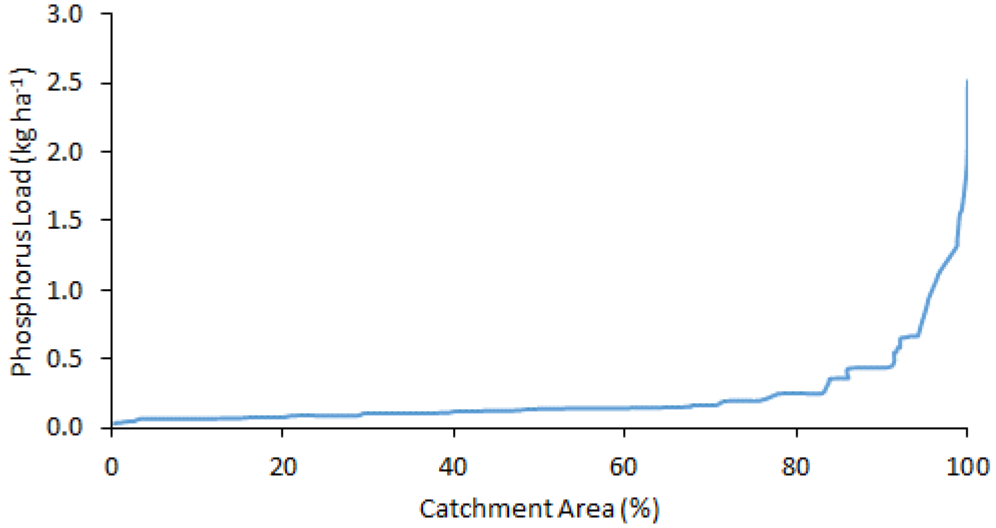

Figure 8 Percentage of the agricultural land within the catchment with different annual average agricultural phosphorus loads. Pollutant loads and areas are calculated at farm scale. Pollutant loads are with current implementation (Scenario 2).

Table 18 Percentage reductions in the annual average agricultural phosphorus and nitrate loads due to land use change scenarios. Measure implementation on the land not subject to land use change is either current implementation (Scenario 2) or all measures (Scenario 6). Reductions are expressed relative to Scenario 2 (current measure implementation) and are the combined effect of the land use change and any increase in measure implementation.

Land Use Change (LUC) targeting	Phosphorus		Nitrate	
	Measure implementation on non-LUC land		Measure implementation on non-LUC land	
	Current (sc. 2)	All Measures (sc. 6)	Current (sc. 2)	All Measures (sc. 6)
No land use change	0	38	0	14
All arable farms not receiving poultry manure converted to zero-input grassland	9	42	6	19
All arable farms not receiving poultry manure converted to woodland	11	44	7	20
30% most intensively phosphorus polluting land (i.e. highest kg P ha^{-1} loss at farm scale) converted to zero-input grassland	45	60	31	39
30% least intensively phosphorus polluting land (i.e. lowest kg P ha^{-1} loss at farm scale) converted to zero-input grassland	7	40	26	36
30% of land on farms converted to zero-input grassland	20	46	27	36

Summary

The Farmscoper tool has been used to determine annual average phosphorus and nitrate losses from agriculture in the River Wye catchment, and the impacts of various scenarios of measure implementation and land use change on these pollutant losses.

Key Findings

The default input data in Farmscoper were modified to account for local information on soil phosphorus indices and to reflect on-going increases in poultry numbers. The default poultry numbers in Farmscoper, based on Defra Agricultural Survey data for 2019, were around 11 million birds, but APHA data obtained by Natural England suggested there are closer to 30 millions birds. This APHA data results in poultry excreta being the dominant livestock source of excreta in the catchment for both phosphorus (63% of all excreta) and nitrate (49%). There is enough excreta for the equivalent of one third of the agricultural area in the catchment to be stocked at close to 170 kg N ha^{-1} (the regulatory limit inside NVZ areas).

Despite the significant excreta and manure inputs into the catchment, Farmscoper predicts over half of the phosphorus loss is associated with the movement of sediment, and thus controlling soil loss is a key mechanism for reducing overall phosphorus losses, with cover cropping the most effective measure as it limits erosion on land that might otherwise be bare over-winter.

Full regulatory compliance was predicted to have a small impact relative to Farmscoper's estimate of current measure implementation (6% reduction in phosphorus losses, 2% for nitrate). If current levels of compliance and background mitigation implementation are much lower than assumed in Farmscoper, then achieving full compliance could result in greater reductions (up to 15% for phosphorus, in the extreme case of zero current implementation). More local information on compliance and implementation may thus be beneficial for determining the impacts of potential future scenarios.

Adoption of the CSF recommended measures reduces phosphorus losses by around 14%, but the use of the top 5 most effective measures within Farmscoper achieves greater reductions (around 22%). This difference is because the most effective measure in Farmscoper's library (cover crops) is not in the CSF recommended list, whilst the list does include some measures that may be locally important, but are assumed by Farmscoper to have limited impact at catchment scale (e.g. steading and track management).

Implementation of all measures within the Farmscoper library achieves reductions in phosphorus of over 35%, but it should be noted this is really a theoretical limit as in reality it would be impractical to implement all the measures (partly due to the cumulative land take of the various biodiversity options making farming of the remaining field area less viable).

Large scale land use change (30% of the catchment) can achieve phosphorus reductions of over 40% if targeted at the most polluting farms, and almost 60% if combined with measures on the non-converted land, whilst using a non-targeted approach does not quite reach a 20% reduction (without further measures).

The effectiveness of targeted land use change (and targeted measure implementation) is because Farmscoper predicts that over half the total phosphorus loss comes from just 15% of the land. Reducing the amount of manure applied on high-risk areas would be one small way of controlling losses without altering livestock numbers or farming within the catchment.

Limitations and Assumptions

Farmscoper has a limited number of soil types, which were designed to capture key differences in pollutant pathways, and these strongly control the phosphorus load due to the importance assigned to drain flow for transporting phosphorus. Identification of the high-risk soil types within the Wye, and the presence and extent of artificial drainage, would thus be a useful step in controlling losses (and validating the Farmscoper results for the Wye). Farmscoper assumes a connectivity factor of 0.9 for phosphorus and sediment losses in drain flow (i.e. only 90% of the material mobilised and traveling through drain flow reaches the watercourse), which is the default value from the PSYCHIC model. However, Zhang et al., (2016) have suggested this drain connectivity ranges from 0.52 to 0.89 at Water Management Catchment scale, which could potentially reduce the overall phosphorus losses in the Wye by up to 20% given the importance of this pathway.

Previous work has suggested that the soils in the Wye may be heavily compacted, which would increase surface runoff and alter the effectiveness and impacts of mitigation measures. It would be useful to assess the current extent of compaction across the catchment, and if it is different to national rates, use Farmscoper or other tools to assess the consequences of this.

The RePhoKUs project has suggested that fertiliser rates in the Wye catchment may be higher than national averages used in Farmscoper, which would lead to higher losses. Other management factors (e.g. proportion of manure managed as slurry, uptake of measures) are also potentially different from national values, which would impact on predicted pollutant losses.

Phosphorus concentrations in water travelling below the root zone and particulate soil phosphorus data are based on national monitoring data and national soil datasets respectively. Over time, given the higher-than-average manure inputs in the Wye, these national values will become less appropriate for the Wye and Farmscoper will underpredict phosphorus losses.

The assessment of compliance (scenario 3) was based on the Farming Rules for Water, which are only applicable in England, and assumptions are made about the implementation of measures that could be considered “reasonable precautions to prevent diffuse pollution from occurring” as required by these rules.

There is a large amount of poultry manure produced within the Wye catchment, which is mostly spread on land from other farms - but which farms receive manure, and how much, will vary from year to year. There is limited information available on where manure is spread, or how much is exported out of the catchment (zero export is assumed here - recent voluntary private-sector pledges to export manure have not been accounted for). Farmscoper simplifies this complex situation by assuming the pig and poultry farms have sufficient land to spread their own manure at an appropriate rate, with the land on other farm types reduced accordingly. Whilst this does not affect the overall pollutant losses predicted, it does affect the average farm size and absolute farm loads and the apportionment of loads between farm types reported here. The reductions achieved on many farms will be a combination of the source farm type results and the results for the poultry farm type, depending upon the amount of manure imported.

Losses in Farmscoper are derived from climate data for 1981-2010 and rainfall erosivity relationships derived from weather data for 1990-2000 (Davison et al., 2005). More recent changes in climate and the intensity of rainfall events will contribute to changes in pollutant losses and uncertainty in the current predicted values.

References

Atkins, 2014. River Wye SAC Nutrient Management Plan Evidence base and options appraisal. 149pp River_Wye_NMP_final_report_v3_14052014.pdf

Environment Agency and Natural England. 2019. Nutrient Management Plan: River Wye. https://www.gov.uk/government/publications/nutrient-management-plan-river-wye

Defra. 2024. Structure of the agricultural industry in England and the UK at June. https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

Davison, P, Hutchins, M.G., Anthony, S.G., Betson, M., Johsnon, C., Lord, E.I. 2005. The relationship between potentially erosive storm energy and daily rainfall quantity in England and Wales. Science of the total environment, 344, 15-25.

Environment Agency, 2022. River Wye Management Catchment Integrated Data Analysis Report. 55pp. https://consult.environment-agency.gov.uk/west-midlands/river-wye-water-quality/supporting_documents/Wye_Report_Q3_2021_22.pdf

Gooday, R.D., Anthony, S.G., Chadwick, D.R., Newell-Price, P., Harris, D., Duethmann, D., Fish, R., Collins, A.L., Winter, M. 2014. Modelling the cost-effectiveness of mitigation methods for multiple pollutants at farm scale. Science of the Total Environment, 468-469, 1198-1209.

PAAG Professional Agricultural Analysis Group, 2019. Collation of data from routine soil analysis in the UK 2018/2019. 13pp. https://www.triedandtested.org.uk/tried-and-tested/paag-reports/paag-report-2018-19/

Welsh Government. 2021. Agricultural small area statistics: 2002 to 2020. https://www.gov.wales/agricultural-small-area-statistics-2002-2020

Wilson, L., Gooday, R., Stocks, C. & Palmer, L (2023) Monitoring Decision Support Tool (M-DST) Validation, Environment Agency Project WLB-625 – ENVWLB00625R

Withers, P.J.A., Rothwell, S.A., Forber, K.J. & Lyon, C. 2022. Re-focusing Phosphorus use in the Wye Catchment. RePhoKUs. 32pp. DOI: 10.5281/zenodo.6598122.svg

Zhang, Y., Collins, A.L., Hodgkinson, R. 2016. Use of farm survey returns from the Demonstration Test Catchments to update modelled predictions of sediment and total phosphorus loadings from subsurface drains across England and Wales. Soil Use and Management, 32, 127-137.

GLOSSARY

BSFP	British Survey of Fertiliser Practice
FRfW	Farming Rules for Water
FYM	Farmyard Manure
Loss	The amount of nitrate, phosphorus etc leaving the agricultural system as a pollutant. Comparable to the term ‘emissions’, although that is more commonly used to refer to losses to air. Water-borne losses are those to the watercourse or to groundwater, and do not account for retention or any other in-stream processes.
Load	The amount of nitrate, phosphorus etc leaving the agricultural system as a pollutant, expressed per hectare of the source farm or catchment. Water-borne losses are those to the watercourse or to groundwater, and do not account for retention or any other in-stream processes.
Manure	All types of managed manure – slurry, FYM, broiler litter, poultry manure etc.
NVZ	Nitrate Vulnerable Zone

APPENDIX

Representation of current uptake

Table 19 and Table 20 are used to derive the percentage current implementation rate of the measures in the Farmscoper library.

Table 19 Scoring system used for determining mitigation measure implementation, in combination with Table 20

Category	Value
A	0
B	2
C	10
D	25
E	50
F	80
G	100

Table 20 Current implementation of mitigation measures. Base rate varies by soil type, which can then be raised or lowered one or more categories depending upon if the farm is within an NVZ or is a grazing farm type. The percentage rates assigned to the letter categories are shown in Table 19. Only measures with a non-zero rate are included in this table.

Mitigation Measures Name	Base value by soil type Free Draining	Base value by soil type Other	Modifiers NVZ	Modifiers Intensive Grazing	Modifiers Extensive Grazing
Establish cover crops in the autumn	D	C	0	-1	-1
Early harvesting and establishment of crops in the autumn	E	E	0	0	0
Cultivate land for crops in spring rather than autumn	F	B	0	0	0
Adopt reduced cultivation systems	C	E	0	-1	-1
Cultivate compacted tillage soils	E	E	0	-1	-1
Cultivate and drill across the slope	D	D	0	0	0
Leave autumn seedbeds rough	D	D	0	-1	-1
Manage over-winter tramlines	D	D	0	-1	-1
Establish in-field grass buffer strips	C	C	0	0	0
Establish riparian buffer strips	D	D	0	-1	-1
Loosen compacted soil layers in grassland fields	E	E	0	0	0
Allow grassland field drainage systems to deteriorate	A	B	0	0	0
Ditch management on arable land	A	E	0	0	0
Ditch management on grassland	A	D	0	0	0
Improved livestock through breeding	C	C	0	0	0
Fertiliser spreader calibration	E	E	1	0	-1
Use a fertiliser recommendation system	F	F	1	0	-1
Integrate fertiliser and manure nutrient supply	E	E	1	0	-1

Mitigation Measures Name	Base value by soil type Free Draining	Base value by soil type Other	Modifiers NVZ	Modifiers Intensive Grazing	Modifiers Extensive Grazing
Do not apply manufactured fertiliser to high-risk areas	E	E	1	0	-1
Avoid spreading manufactured fertiliser to fields at high-risk times	A	A	1	0	0
Use manufactured fertiliser placement technologies	C	C	0	0	0
Incorporate a urease inhibitor into urea fertilisers for grassland	B	B	0	0	-1
Incorporate a urease inhibitor into urea fertilisers for arable land	B	B	0	0	-1
Use clover in place of fertiliser nitrogen	C	C	0	0	0
Reduce dietary N and P intakes: Dairy	C	C	0	0	0
Reduce dietary N and P intakes: Pigs	F	F	0	0	0
Reduce dietary N and P intakes: Poultry	F	F	0	0	0
Adopt phase feeding of livestock: Dairy	F	F	0	0	0
Adopt phase feeding of livestock: Pigs	F	F	0	0	0
Reduce the length of the grazing day/grazing season	C	C	0	0	0
Extend the grazing season for cattle	C	C	0	0	0
Reduce field stocking rates when soils are wet	F	F	0	0	0
Move feeders at regular intervals	E	E	0	0	0
Construct troughs with concrete base	B	B	0	0	0
Increase scraping frequency in dairy cow cubicle housing	C	C	0	0	0

Mitigation Measures Name	Base value by soil type Free Draining	Base value by soil type Other	Modifiers NVZ	Modifiers Intensive Grazing	Modifiers Extensive Grazing
Additional targeted bedding for straw-bedded cattle housing	C	C	0	0	0
Washing down of dairy cow collecting yards	D	D	0	0	0
Frequent removal of slurry from beneath-slat storage in pig housing	B	B	0	0	0
Install air-scrubbers: mechanically ventilated pig housing	B	B	0	0	0
Install air-scrubbers: mechanically ventilated poultry housing	B	B	0	0	0
More frequent manure removal from laying hen housing	C	C	0	0	0
In-house poultry manure drying	C	C	0	0	0
Increase the capacity of farm slurry stores	A	A	1	0	0
Install covers to slurry stores	C	C	0	0	0
Allow cattle slurry stores to develop a natural crust	F	F	0	0	0
Minimise the volume of dirty water produced	D	D	0	0	-1
Compost solid manure	B	B	0	0	0
Site solid manure heaps away from watercourses/field drains	F	E	1	0	0
Store solid manure heaps on an impermeable base & collect effluent	C	C	0	0	0
Cover solid manure stores with sheeting	B	B	0	0	0
Use liquid/solid manure separation techniques	B	B	0	0	0
Manure Spreader Calibration	D	D	1	0	-1
Do not apply manure to high-risk areas	F	F	1	0	-1

Mitigation Measures Name	Base value by soil type Free Draining	Base value by soil type Other	Modifiers NVZ	Modifiers Intensive Grazing	Modifiers Extensive Grazing
Do not spread slurry or poultry manure at high-risk times	A	A	1	0	-1
Use slurry band spreading application techniques	C	C	0	0	-1
Use slurry injection application techniques	B	B	0	0	-1
Do not spread FYM to fields at high-risk times	A	A	1	0	-1
Incorporate manure into the soil	D	D	0	0	-1
Fence off rivers and streams from livestock	E	E	0	0	-1
Construct bridges for livestock crossing rivers/streams	F	F	0	0	0
Re-site gateways away from high-risk areas	D	D	0	0	0
Farm track management	E	E	0	0	-1
Establish new hedges	B	B	0	0	0
Establish and maintain artificial wetlands - steading runoff	A	B	0	0	0
Irrigate crops to achieve maximum yield	D	B	0	0	0
Management of woodland edges	B	B	0	0	0
Management of in-field ponds	B	B	0	0	0
Management of arable field corners	B	B	0	0	0
Plant areas of farm with wild bird seed / nectar flower mixtures	B	B	0	0	0
Beetle banks	B	B	0	0	0
Uncropped cultivated margins	B	B	0	0	0
Skylark plots	B	B	0	0	0
Uncropped cultivated areas	B	B	0	0	0
Unfertilised cereal headlands	B	B	0	0	0

Mitigation Measures Name	Base value by soil type Free Draining	Base value by soil type Other	Modifiers NVZ	Modifiers Intensive Grazing	Modifiers Extensive Grazing
Unharvested cereal headlands	B	B	0	0	0
Under-sown spring cereals	B	B	0	0	0
Management of grassland field corners	B	B	0	0	0
Leave residual levels of non-aggressive weeds in crops	B	B	0	0	0
Use correctly inflated low ground pressure tyres on machinery	E	E	0	-1	-1
Locate out-wintered stock away from watercourses	C	C	0	0	0
Use dry-cleaning techniques to remove solid waste from yards	A	A	0	0	-1
Capture of dirty water in a dirty water store	F	F	0	0	-1
Irrigation/water supply equipment is maintained, and leaks repaired	E	C	0	0	0
Avoid irrigating at high-risk times	D	B	0	0	0
Use efficient irrigation techniques (boom trickle, self-closing nozzles)	C	A	0	0	0
Use high sugar grasses	C	C	0	0	0

Representation of compliance alongside current uptake

Farmscoper contains an estimate of the current implementation rates for all measures in its measure library. These estimates are based on national survey data (e.g. Defra Farm Practice Surveys, British Survey of Fertiliser Practice) and agri-environment scheme agreement data, some of which is stratified by farm type. Implementation rates are based on the categorised scoring system used within Farmscoper, with different values potentially used for the soil types within Farmscoper. These rates are potentially raised or lower by one or more categories within NVZ areas or on livestock farms, where this is justified by the available evidence or based upon expert opinion.

The scenarios assumed full compliance with regulations (i.e. 100% implementation rates for those measures associated with compliance) and the default rates for the other mitigation measures. This was achieved by selecting ‘Use prior implementation tables’ within Farmscoper_Evaluate, and then setting the values on the ‘Settings-Priors’ tab to ‘G’ for the Farming rules for Water measures (so that the implementation rate would be 100%) and to ‘7’ for the NVZ measures (so that uptake would be increased by 7 bands, i.e. to ‘G’ value, if the farm was set to be within an NVZ). A screenshot of part of the ‘Settings-Priors’ tab is shown in Figure 9 to help show this. Note that this approach was designed to allow for both compliance and background uptake, and the automatic creation of NVZ farms through Farmscoper_Upscale. To simply specify a fixed rate for each measure, prior uptake could have been set to the desired value on the ‘Method List’ tab and the ‘Use prior implementation tables’ option disabled.

ID	Method Name	Baseline Values: Free Draining	Baseline Values: Other	Modifiers: NVZ	Modifiers: Intensive Grazing	Modifiers: Extensive grazing
4	Establish cover crops in the autumn	D	C		-1	-1
5	Early harvesting and establishment of crops in the autumn	E	E			
6	Cultivate land for crops in spring rather than autumn, retaini	F	B			
7	Adopt reduced cultivation systems	C	E		-1	-1
8	Cultivate compacted tillage soils	E	E		-1	-1
9	Cultivate and drill across the slope	D	D			
10	Leave autumn seedbeds rough	D	D		-1	-1
11	Manage over-winter tramlines	D	D		-1	-1
13	Establish in-field grass buffer strips	C	C			
14	Establish riparian buffer strips	D	D		-1	-1
15	Loosen compacted soil layers in grassland fields	E	E			
16	Allow grassland field drainage systems to deteriorate	A	B			
180	Ditch management on arable land	A	E			
181	Ditch management on grassland	A	D			
19	Improved livestock through breeding	C	C			
20	Use plants with improved nitrogen use efficiency	A	A			
21	Fertiliser spreader calibration	E	E	7		-1
22	Use a fertiliser recommendation system	G	G			
23	Integrate fertiliser and manure nutrient supply	G	G			
25	Do not apply manufactured fertiliser to high-risk areas	G	G			
26	Avoid spreading manufactured fertiliser to fields at high-risk	G	G			

Score	Value
A	0
B	2
C	10
D	25
E	50
F	80
G	100

Update Prior Implementation on 'Method List' worksheet

Figure 9 How to represent full compliance with some mitigation measures, whilst leaving implementation rates for other measures to vary by soil, farm type and whether in or out of Nitrate Vulnerable Zone (NVZ).

Measures implemented to get the maximum impact possible through mitigation measures.

- Establish cover crops in the autumn
- Early harvesting and establishment of crops in the autumn
- Cultivate land for crops in spring rather than autumn, retaining over-winter stubbles
- Adopt reduced cultivation systems
- Cultivate compacted tillage soils
- Cultivate and drill across the slope
- Leave autumn seedbeds rough
- Manage over-winter tramlines
- Establish in-field grass buffer strips
- Establish riparian buffer strips
- Loosen compacted soil layers in grassland fields
- Allow grassland field drainage systems to deteriorate
- Improved livestock through breeding
- Use a fertiliser recommendation system
- Integrate fertiliser and manure nutrient supply
- Do not apply manufactured fertiliser to high-risk areas
- Avoid spreading manufactured fertiliser to fields at high-risk times
- Use manufactured fertiliser placement technologies
- Do not apply P fertilisers to high P index soils
- Reduce dietary N and P intakes: Dairy
- Reduce dietary N and P intakes: Pigs
- Reduce dietary N and P intakes: Poultry
- Adopt phase feeding of livestock: Dairy
- Adopt phase feeding of livestock: Pigs
- Reduce the length of the grazing day/grazing season
- Reduce field stocking rates when soils are wet
- Move feeders at regular intervals
- Construct troughs with concrete base
- Increase the capacity of farm slurry stores to improve timing of slurry applications
- Minimise the volume of dirty water produced (sent to slurry store)
- Site solid manure heaps away from watercourses/field drains
- Store solid manure heaps on an impermeable base and collect effluent
- Cover solid manure stores with sheeting
- Use liquid/solid manure separation techniques
- Use poultry litter additives
- Do not apply manure to high-risk areas
- Do not spread slurry or poultry manure at high-risk times
- Use slurry injection application techniques
- Do not spread FYM to fields at high-risk times
- Incorporate manure into the soil

- Fence off rivers and streams from livestock
- Construct bridges for livestock crossing rivers/streams
- Re-site gateways away from high-risk areas
- Establish new hedges
- Establish and maintain artificial wetlands - steading runoff
- Management of woodland edges
- Management of in-field ponds
- Management of arable field corners
- Plant areas of farm with wild bird seed / nectar flower mixtures
- Beetle banks
- Uncropped cultivated margins
- Uncropped cultivated areas
- Unfertilised cereal headlands
- Unharvested cereal headlands
- Undersown spring cereals
- Management of grassland field corners
- Use correctly-inflated low ground pressure tyres on machinery
- Locate out-wintered stock away from watercourses
- Use dry-cleaning techniques to remove solid waste from yards prior to cleaning
- Capture of dirty water in a dirty water store
- Avoid irrigating at high-risk times
- Use efficient irrigation techniques (boom trickle, self-closing nozzles)
- Better health planning: beef
- Better health planning: sheep
- Improve livestock through genetic modification